Watershed Monitoring for the Northwest Forest Plan

Data Summary Interpretation 2004
North Cascades Province

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INTRODUCTION

The Aquatic and Riparian Effectiveness Monitoring Program (AREMP or the monitoring program) is a multi-federal agency program designed to assess the effectiveness of the Northwest Forest Plan's Aquatic Conservation Strategy (USDA, USDI 1994) in maintaining or restoring the condition of watersheds in the Northwest Forest Plan area. To evaluate the effectiveness of the strategy, the monitoring program determines whether key processes that maintain aquatic and riparian habitats are intact (Reeves et al. 2004). This information is used to assess the current condition of watersheds and to monitor changes in condition through time. If the strategy is effective, then the overall condition of watersheds across the region should either remain the same as it was when the strategy was implemented in 1994, or it should improve.

Watershed condition is evaluated at the USGS 6th-field hydrologic unit subwatershed (hereafter referred to as watershed) scale using a province-specific decision support model that aggregates data on in-channel, riparian and upslope attributes. These attributes are indicators of watershed processes. A watershed is defined as being in "good" condition if the physical attributes are adequate to maintain or improve biological integrity, with a focus on diversity and abundance of native aquatic and riparian-dependent species, salmonids in particular.

The purpose of this report is to provide local units with the results of our data collection and decision support modeling efforts for watersheds surveyed in the North Cascades physiographic province during the 2004 field season (Table 1). Separate reports were prepared for each physiographic province (Figure 1). Included in this report are overviews of field (in-channel) data collection methods and calculations performed on the data, GIS data collection methods, the decision support model used to evaluate watershed condition, and a guide on how to interpret the model results. Watershed-specific summary tables (a printable summary of the watershed condition scores and field data from the 2004 field season), maps, photos, raw field data files and GIS data accompany this report on the AREMP website. Benthic macroinvertebrate and periphyton samples were collected in the field, but are currently at the laboratory being analyzed and were not available to be included in this report or the model output. Links to additional documents pertaining to the monitoring program and decision support models are available on the website.

New in 2004

In 2004 we had a number of new developments and accomplishments in the monitoring program. These accomplishments include:

- Construction and refinement of the decision support models is complete. The results of this effort are being released for the first time in this report.
- A preliminary assessment of the Northwest Forest Plan's Aquatic Conservation Strategy was completed. In this analysis, we compared the current condition of 250 watersheds in the Plan area with the condition in 1994 when the Plan was implemented. The results of this assessment will be released by the USDA Forest Service Pacific Northwest Research Laboratory in spring 2005.
- In an effort to streamline field protocols and standardize them with the PIBO Effectiveness Monitoring Project, some field methods and the attributes we collect have changed. Changes were made to site layout and site length, number of transects, bankfull width to depth, entrenchment ratio, pool definition, substrate, wood, electrofishing and amphibian

searches. Stream discharge and water samples for phosphorous and nitrogen are no longer collected.

- In 2004, 20 6th-field HUC (Hydrologic Unit Code) watersheds with a total of 104 sites were sampled (Table 1). In addition, field crews conducted resurveys at 20 sites in 13 watersheds as a part of our data quality control program, and 20 trend surveys from 2003 watersheds, which are used to increase our ability to detect trend (Figure 1).

Table 1. Watersheds (6th Field HUC) surveyed by the Aquatic and Riparian Effectiveness Monitoring Program during the 2004 field season.

Province	USGS HUC	Watershed Name	5th Field Watershed	Administrative Unit
Franciscan	171003100602	Shasta Costa Creek	Rogue River	Siskiyou NF
Franciscan	171003120106	Boulder Creek	Upper Chetco River	Siskiyou NF
High Cascades	180102060502	Fall Creek (Camp)	Klamath - Iron Gate	Medford BLM
High Cascades	171003070402	Clarks Fork / Fourbit Creek	Big Butte Creek	Rogue River NF
High Cascades	171003070112	Lower Mill Creek	Upper Rogue River	Rogue River NF
High Cascades	171003010402	Bear Creek	Clearwater	Umpqua NF
Klamath/Siskiyou	171003090203	Star Gulch	Upper Applegate River	Medford BLM
Klamath/Siskiyou	171003020902	Middle Creek	Lower Cow Creek	Roseburg BLM
Klamath/Siskiyou	180102110103	Little Trinity River	Main Trinity River	Shasta-Trinity NF
Klamath/Siskiyou	180102110404	Stoney Creek	Stuart Fork	Shasta-Trinity NF
North Cascades	171100090201	Upper NF Skykomish River	Skykomish River Forks	Mt. Baker-Snoqualmie NF
North Cascades	170200090202	Fish Creek	Upper Chelan	Wenatchee NF
Olympic Peninsula	171100180301	Upper Big Quilcene River	Big Quilcene River	Olympic NF
OR/WA Coast	170900070201	Upper Rickreall Creek	Rickreall Creek	Salem BLM
Western Cascades	170900020101	Layng Creek	Row River	Umpqua NF
Western Cascades	171003011104	Emile Creek	Little River	Umpqua NF
Western Cascades	171003010801	Steamboat / City Creek	Steamboat Creek	Umpqua NF
Western Cascades	170900010902	Fall / Hehe Creek	Fall Creek	Willamette NF
Western Cascades	170900040201	Upper Separation Creek	Horse Creek	Willamette NF
Western Cascades	170900040102	Fish Lake Creek (Hackleman)	Upper McKenzie River	Willamette NF

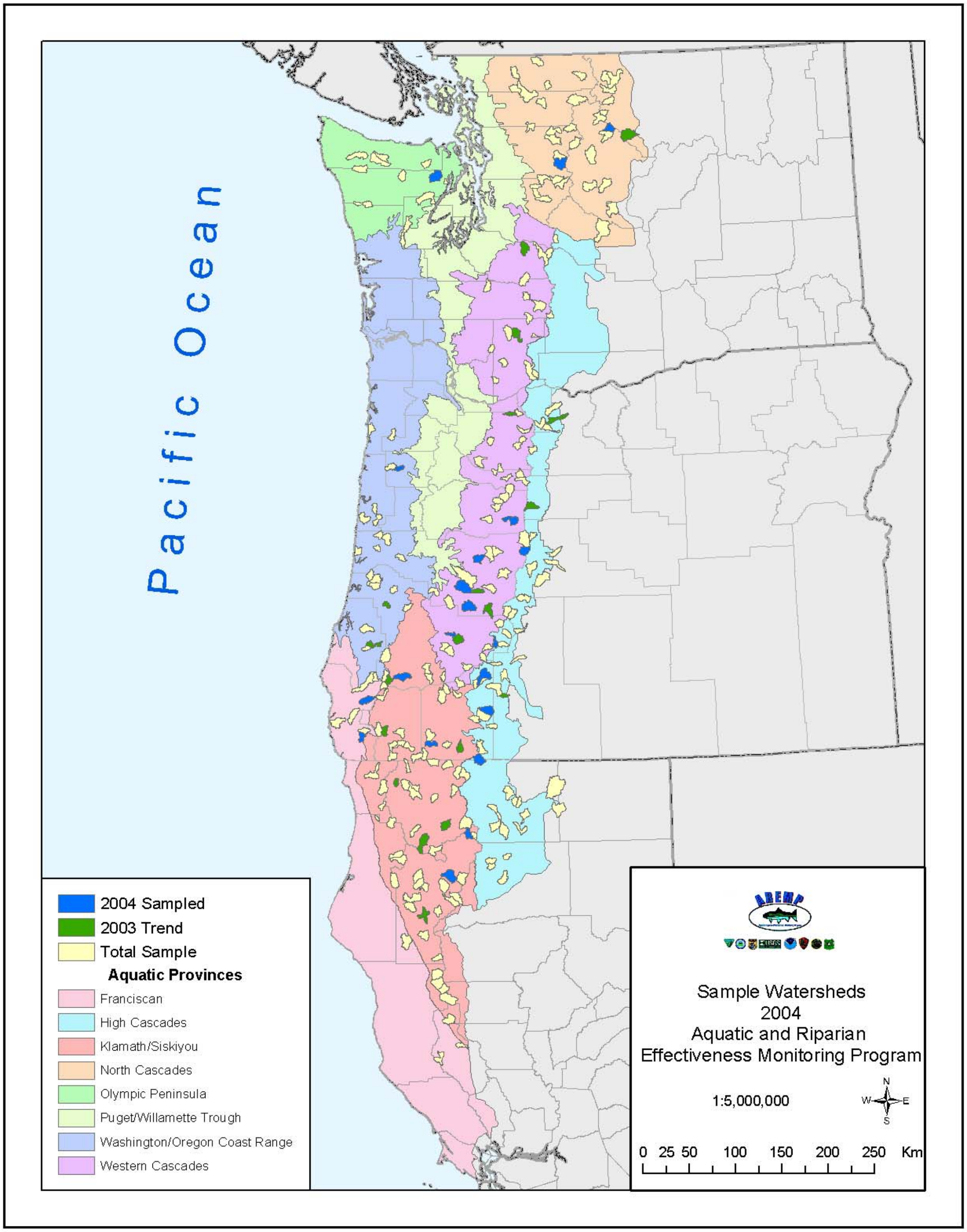


Figure 1. Randomly selected watersheds included in the Aquatic and Riparian Effectiveness Monitoring Program sampling. Watersheds sampled during the 2004 field season are highlighted in blue, resampled watersheds are highlighted in green and the provinces of the Northwest Forest Plan are color coded in the background.

METHODS

Study Design

Monitoring is conducted in 250 randomly selected 6th field watersheds, each approximately 10,000-40,000 acres in size (Figure 1). To be included in the sample, a watershed must contain a minimum 25% federal ownership along the stream, based on the 1:100,000 stream layer. The program's goal is to monitor 50 watersheds each year on a five-year rotation (Reeves et al. 2004). However, we sampled only 20 watersheds this year because of funding limitations. Data were collected for in-channel, riparian, and upslope attributes. In-channel attributes were collected at randomly-selected sites (5 sites on average) within each watershed. Upslope and riparian data were collected from vegetation and roads layers using GIS. The evaluation of upslope and riparian conditions in watersheds was tailored to specific physiographic provinces. The physiographic boundaries used in this analysis were developed from those used in the aquatic ecosystem assessment, which were based on broadly drawn precipitation and geologic areas (FEMAT 1993).

Field Data Collection

Field data provide information on the physical habitat and the biota. Physical habitat indicators include: bankfull width to depth ratio, entrenchment ratio, pool frequency, sinuosity, gradient, wood frequency, percent pool-tail fines, and substrate D_{50}. Water chemistry data were also collected. Biological indicators include: periphyton, benthic macroinvertebrates, aquatic and terrestrial amphibians, and fish.

Three types of surveys were conducted during 2004, with each type referring to a different point in time and a different purpose for the data collected. However, the data collection protocols were the same for all survey types. The survey types (with definitions) are as follows:

- Initial Surveys – These surveys were conducted at sites that the monitoring program had not previously surveyed. The sites were surveyed within a subset of the 250 randomly selected watersheds used to assess the success of the Northwest Forest Plan.
- Quality Assurance/Quality Control (QAQC) Surveys – These surveys were conducted at sites that were randomly selected from the initial surveys. The intent of these surveys was to determine the abilities of field crews to measure the same segment of a stream consistently. These surveys always occurred after the Initial Survey and were conducted by an independent crew. During the resample visit, only the start point of the survey was established. All other sampling was conducted in the same way as the original survey.
- Trend Surveys – These surveys were conducted during the 2004 field season at 20 sites that had both an Initial Survey and a QAQC Survey during the 2003 field season. These sites were surveyed by a different field crew at each subsequent survey. The intent of these surveys is to assess trend in a subset of the 250 watersheds prior to completion of the full cycle of sampling. Results of the trend analysis will not be presented here, but will be available on our web site when it becomes available.

For the initial surveys, eighty potential sampling sites were randomly chosen along the stream network in each watershed and identified with a GPS coordinate. In the field, sites were considered for sampling in numerical order, omitting sites that could not be sampled. The goal was to sample as many sites as possible within the watershed. However, because of logistical constraints, we usually sampled the first six to eight accessible sites. Typically, fewer sites were sampled in watersheds that required a lot of time traveling to remote locations. The only reasons that a site was not sampled was if it was located on private land or could not be accessed due to private land; it was located on a glacier or in a lake; it was not safely accessible; the stream was too small to sample (less than 1 meter wetted width and 0.1 meters deep in riffle habitats); the stream was too large to physically sample (pools were too deep to wade, picking up pebbles on the bottom would require a wet suit, and wading across the stream was only possible in a few riffles); or travel time on foot to and from the site was greater than 4 hours.

The length of each site was approximately 20 times the bankfull width (using 2 m bankfull width categories) with minimum and maximum reach lengths of 160 and 480 m. Sampling was conducted at 21 transects (11 major and 10 intermediate transects), equally-spaced along the length of the sample reach (Figure 2). We established the start point for sampling at the GPS coordinate and measured the reach upstream along the thalweg one transect at a time. The end point was established at the 21st transect location. Side channels were included in the survey only if they began and ended within the survey reach and the average bankfull width of the side channel was at least 20% of the bankfull width of the primary channel. We documented the start of the reach by recording the GPS coordinate with a Garmin GPS 12-map, taking a minimum of four photos from the start point (facing left bank, downstream, right bank and upstream), and posting a marker near the start point.

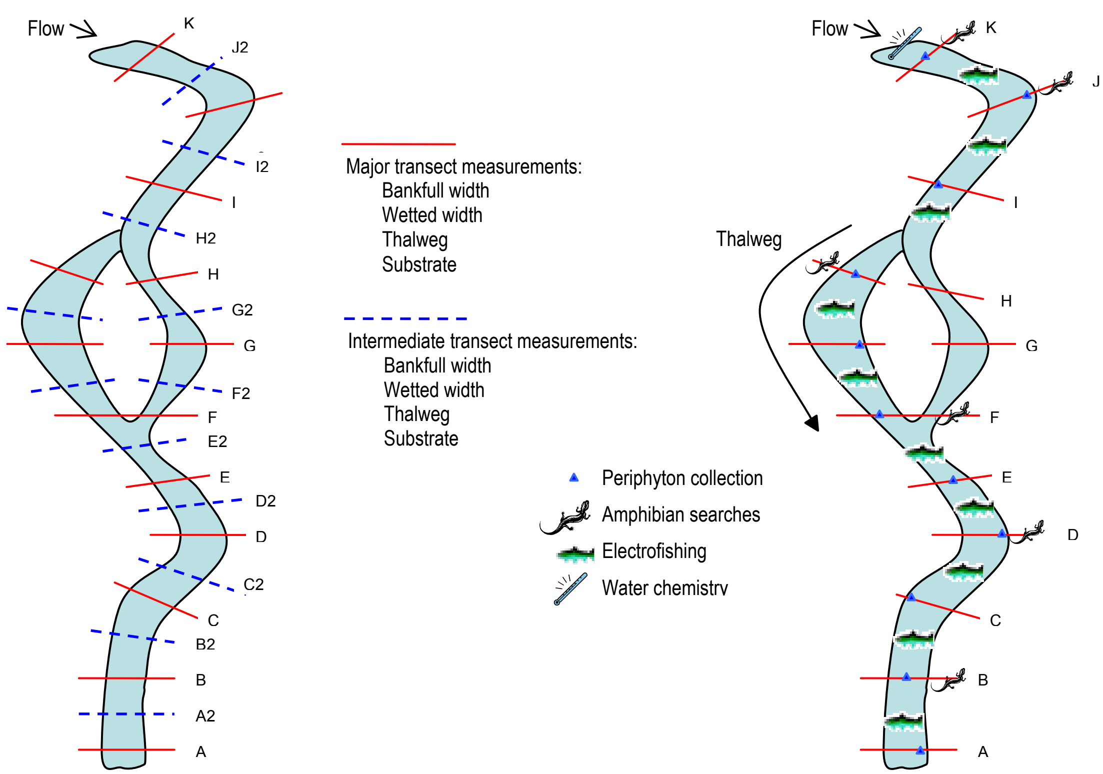


Figure 2. Overview of site layout and sampling strategy. The start point is established at the downstream end of the reach at transect A. Major and minor transects are equally spaced along the thalweg. Measurements and sampling conducted at each transect is outlined in the figure.

Physical Habitat

Bankfull widths, valley length, bed elevations and one cross-sectional profile were measured in each sample site using a laser rangefinder. We measured bankfull width at each of the eleven major transects and calculated average bankfull width of the reach based on these measurements (Table 2). Additional points were measured at the wetted edges and thalweg of major transects and at the thalweg of minor transects. Sinuosity was calculated as the length of the reach along the thalweg measured with a measuring tape, divided by the straight line distance between the thalweg at the start of the reach to the thalweg at the end of the reach, measured with the laser. Reach gradient was determined by the change in elevation of the bed surface at the thalweg from the bottom to the top of the reach, divided by the reach length.

At each reach, data from one channel cross-section extending beyond the flood prone elevation were used to calculate bankfull width to depth ratio and entrenchment ratio. The cross-section was located at the first inflection point of the first riffle encountered, where the channel was relatively straight and did not have secondary channels, human or animal crossings, deflectors or unusual constrictions that narrow the channel or create exceptionally wide backwater conditions. We defined the floodprone height as two times the maximum bankfull elevation, and the floodprone width as the perpendicular distance between the floodprone constraints. At the cross-section, eleven equally-spaced depth measurements were taken on increment, within and perpendicular to the bankfull channel constraints (Figure 3). Additional measurements were taken at both wetted edges and the thalweg. Upslope of the bankfull elevation, measurements were taken to capture significant slope changes and the floodprone constraints. The bankfull width at the cross section was divided by the flood prone width to determine the entrenchment ratio for the reach (Table 2).

The locations of each pool-tail crest, maximum pool depth and pool head were captured with the laser rangefinder. In 2004, pools were defined as being concave in profile laterally and longitudinally; bound by a head and a tail crest; having a water surface slope close to 0%; occupying greater than 90% of the wetted channel width; having a length greater than its width; a maximum depth at least 1.5 times the pool tail depth; and only including pools containing the thalweg. Pool measurements were used to calculate pool frequency and residual pool depths (Table 2). Residual pool depth is the elevation change from the thalweg at the pool tail crest to the deepest part of the pool.

Substrate particles for the D_{16}, D_{50} and D_{84} calculations were measured using a modification of the Environmental Protection Agency's Environmental Monitoring and Assessment Program substrate protocol (Peck et al. 1999). Five substrate particles were collected from each of the 21 transects at 10%, 30%, 50%, 70% and 90% of the distance across the bankfull channel. Each particle was measured along its intermediate axis with a meter stick. Percent fines (particles less than 2 mm diameter) were measured in the tails of scour pools as described by the USDA Forest Service Region 5 SCI protocol (1998). A 14 inch by 14 inch Klamath grid with 7 equally spaced horizontal and vertical partitions was used to count the number of particles less than 2 mm diameter that were overlain by an intersection. Three grid measurements were taken in each pool tail at 25%, 50% and 75% of the distance across the wetted width, and 10% or one meter (whichever was less) of the pool length upstream of the pool tail crest. These measurements were converted to a percent and then averaged for the first 10 pools (Table 2).

Table 2. Equations used to calculate physical channel attributes. Precision is the number of significant digits used in the calculation

ATTRIBUTE	DEFINITION	EQUATION	PRECISION	# OF MEASUREMENTS
Ave Bankfull Width	Average of the bankfull widths measured at the eleven major transects in the reach.	(Sum of BF widths) / Number of transects	0.1 m	11
Bankfull Width:Depth Ratio	The ratio of bankfull width to bankfull depth at one channel cross-section.	Depth: Area of cross-section / BF width Width: BF width W:D = (BF width)^2 / Area of Cross Section	1	1 width, 10 depth
Entrenchment Ratio	The floodprone width divided by the bankfull width, measured at one channel cross section.	Floodprone width / Bankfull width	0.1	1
Sinuosity	Reach length (measured along the thalweg) divided by the straight valley length (length from the bottom to the top of the reach).	Reach Length / Valley length	0.1	1
Reach Gradient (% Slope)	The elevation change of the substrate surface at the thalweg, from the bottom to the top of the reach divided by the reach length (measured along the thalweg).	(Change in Elevation / Reach Length) * 100	0.1 %	1
Ave Residual Pool Depth	The average of the residual pool depths for all pools.	(Sum of (Pool Max Depth - Pool Tail Depth)) / Number of Pools	0.01 m	All qualifying pools, according to the 2004 AREMP protocol.
Pool Frequency	The number of pools per 100 meters.	(# pools / reach length) * 100	0.001 m^{-1}	All qualifying pools, according to the 2004 AREMP protocol.
Large Wood Frequency	The number of wood pieces greater than .3 m diameter and 3 m long, per 100 meters.	(# pieces / reach length) * 100	0.001 m^{-1}	All qualifying pieces, according to the 2004 AREMP protocol.
Percent PTC Fines	The percent surface fines measured 3 times, 10% or 1 m upstream of the tail crest of a pool.	Average of: (Sum of # Fines Measurements / (150-(sum of # non-measurements))) * 100	0.1 %	The first 10 qualifying pools, according to the 2004 AREMP protocol
D50 Pebble Count	The D_{50} (mm) is the 50th percentile (median distribution) of the substrate particles measured.	Intermediate axis diameter of the median particle collected from particle counts.	1 mm	5 particles per transect on 21 transects.
D84 Pebble Count	The D_{84} (mm) is the 84th percentile. 84% of the substrate particles measured are less than the size calculated.	Intermediate axis diameter of the particle for which 84% of the particles are smaller (84th percentile).	1 mm	5 particles per transect on 21 transects.
D16 Pebble Count	The D_{16} (mm) is the 16th percentile. 16% of the substrate particles measured are less than the size calculated.	Intermediate axis diameter of the particle for which 16% of the particles are smaller (16th percentile).	1 mm	5 particles per transect on 21 transects.

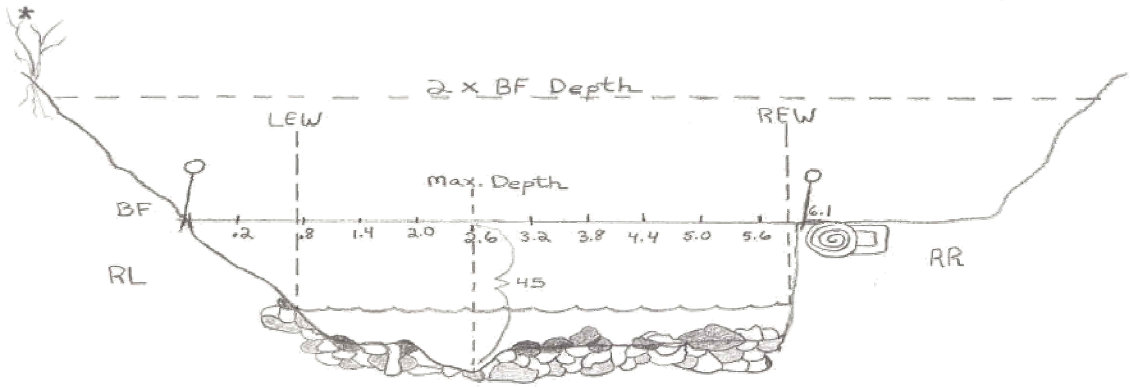


Figure 3. Example cross sectional profile with point labeling (looking downstream).

The large wood protocol was adapted from the Oregon Department of Fish and Wildlife's Stream Habitat Surveys (Moore et al. 1999). Within each reach, pieces of large wood were counted if they had a minimum length of 3 m, and were at least 0.3 m in diameter at one third of the distance from the large end. Length and diameter were visually estimated for each piece. The length and diameter of the first 10 pieces encountered in the reach and every 5th piece thereafter was measured using a measuring tape so that estimates could be corrected. In addition, notes were made on the location of the wood relative to the channel, whether the piece was natural or artificial (part of a man-made structure), whether the piece was single, part of an accumulation (2-4 pieces touching) or part of a jam (5 or more pieces), and the percent of each piece of wood that would be submerged at bankfull flows.

Temperature, dissolved oxygen, pH, conductivity, and specific conductance measurements were collected at the upstream end of each sample site using a YSI 556 multi-probe meter, at five minute intervals for two hours. These measurements were averaged for each reach. Water temperature measurements were recorded hourly from June 15 until September 15 with continuous recording temperature loggers at the lowest point in the watershed on federal land. From these temperature data, the maximum seven-day average temperature was calculated.

Biological Sampling

The periphyton protocol used for field collection and lab analysis is the same as that outlined by Peck et al. (1999). At each of the eleven major transects, periphyton was removed from an assigned sampling location (left, center, or right bank), which alternated at each transect. All attached periphyton inside a 12 cm^2 area was removed by scrubbing for approximately 30-45 seconds with a toothbrush. Material clinging to the toothbrush was washed into a 125 ml bottle. One subsample from each transect was composited into a single sample for each reach. Samples were analyzed by Loren Bahls, Ph.D. in Helena, MT. Each sample was placed on a slide and at least 300 individuals were identified and enumerated for relative abundance assessments. All non-diatom taxa were identified to genus; diatoms were identified to species level.

Benthic macroinvertebrates were collected and analyzed using the protocol described by Hawkins et al. (2001). Using a kick net, we collected two subsamples at randomly-selected locations in each of the first four fast-water units encountered in each reach (8 subsamples total). All rocks larger than a golf ball within each 0.09 m^2 sample area were rubbed to remove attached organisms, and then placed outside the sampling area. The exposed areas of embedded rocks were also rubbed.

After all rocks were rubbed to dislodge attached organisms, the substrate within the sampling area was disturbed for approximately 30 seconds. The eight subsamples were decanted with a sieve, washbasin and bucket to remove inorganic substrates, and composited into a single sample for each reach. Samples were sent to the Bureau of Land Management's National Aquatic Monitoring Center Buglab in Logan, Utah where all insects were identified to the genus level (except Chironomidae, which were identified to subfamily).

At each site, fish and aquatic amphibians were sampled using a single pass with an electrofisher. The goal was to obtain a complete taxa list and species composition for each site within the watershed. All captured animals were identified and enumerated. Animals that were missed were also noted, however the information was not used in the analysis. Animals collected from 20% of the length of the reach were measured, and their condition was estimated using volumetric displacement. Snout-vent lengths were measured for all aquatic amphibians and fork length for each fish captured.

Time and area-constrained searches were conducted for terrestrial amphibians at each site within the watershed. At six of the major transects, searches began at the wetted edge and continued up the bank on either side of the stream, within 2 m of the wetted edge. Each search lasted five minutes (ten minutes total at each transect). During this time, searchers rolled over rocks and logs, and dug through leaves and soil. All captured terrestrial amphibians were identified, counted, measured for snout-vent length, and then returned to the area captured. The protocol used was adopted from Aquatic/Land Interaction Team at the PNW-FSL (Dede Olson, personal communication).

GIS Data Collection

Analyses of road and vegetation attributes were based on Geographic Information System (GIS) coverages. These analyses were tailored to physiographic provinces, which were based on broadly drawn precipitation and geologic areas (FEMAT 1993). Watershed boundaries used in the analysis were from the first draft of the 6th-field Hydrologic Unit Code boundaries developed in 2002. We used 1:24,000 densified stream layers from the Forest Service Region 6 Hydrography framework project. In the North Cascades province, we defined the riparian area by creating a fixed buffer along both sides of all streams on the 1:24,000 stream layer. A 50 m buffer was used on the west side of the Cascades and a 30 m buffer was used on the east side. Upslope area was defined as the area outside of the riparian boundary.

Road Analysis

Road density and frequency of road-stream crossings were calculated using GIS coverages that were pieced together from Forest Service road and BLM ground transportation coverages. The Forest Service coverages, dated 2002, were obtained from each of the national forests in the Forest Plan area. The BLM ground transportation coverage contains data from 1998 that cover all of the BLM districts and other non-BLM lands.

Road densities in upslope and riparian areas were calculated for each watershed. In each of these analyses, the road layer was laid over the riparian buffer. Upslope road density was calculated as the length of road outside the 50 or 30 m buffer divided by the area outside of the buffer. For riparian roads, we determined the percentage of the stream network that had a road within 20 m. This analysis was conducted only on the portions of the stream network that had gradient > 3 percent. We used 30 m digital elevation models compiled by US Geological Survey (2001) to identify these areas.

To determine road-stream crossing frequencies in hazard and non-hazard areas we used land type associations obtained from Wenatchee and Okanogan National Forests on the east side of the Cascade Crest, and a grid produced by Washington Department of Natural Resources (based on Shalstab modeling conducted in 2000) on the west side, to identify areas with high probabilities for mass failure. These coverages were used to generate hazardous area polygons that we overlaid with road and 1:24,000 stream layers. We counted the number of road and stream intersections in both hazard and non-hazard areas and expressed the number of hazardous and non-hazardous road crossings per unit watershed area. Forty-eight sample watersheds spread across the monitoring program area were inspected for potential erroneous crossings from digitizing errors. The percentage of suspected false crossings was less than two percent for the total sample.

Vegetation Analysis

Riparian and upslope vegetation data were collected from coverages developed by the Interagency Vegetation Mapping Project (version 1.0 for the east side and version 2.0 for the west side). These layers were built using Landsat Thematic Mapper remote sensing data and updated using the vegetation change layer developed for the Northwest Forest Plan vegetation monitoring program (Moeur et al. 2005).

The vegetation analyses differed on the west and east side of the Cascades. On the west side of the Cascades, conifer size in riparian areas and percentage of canopy cover were included in the monitoring plan's evaluation of watershed condition. The vegetation coverage was clipped to watershed boundaries and the 50 m riparian buffer was used to calculate the percentage of the forested riparian area covered with conifers with diameter at breast height (DBH) greater than 20 inches, and the percentage of the forested upslope area with canopy cover (conifer and mixed) greater than or equal to 70 percent. Forested area was determined by subtracting non-forested areas, defined as areas incapable of producing trees (such as glaciers, lakes, lava beds or agricultural lands), from the total riparian (area inside the riparian buffer) or upslope (area outside the riparian buffer) area.

On the east side of the Cascades, plant association groups modeled in 2003 by the Forest Service were used to delineate sub-alpine areas and to differentiate upslope mesic/wet areas from dry areas. The following plant association groups were defined as dry: all ponderosa pine and douglas fir, grand fir-pinegrass, grand fir-pinegrass-lupine, grand fir-pinemat manzanita, grand fir-oceanspray-pinegrass, grand fir-mountain snowberry, grand fir-spirea-bracken fern, grand fir-snowberry-pinegrass and shrub-steppe. All other plant association groups were defined as mesic/wet.

The vegetation and plant association coverages were clipped to the watershed boundaries. For the wet/mesic areas, the percentage of upslope area (outside the 30 m buffer) with conifers less than 5 inches DBH was calculated for areas with total cover (conifer and broadleaf) greater than or equal to 50%. In dry areas we calculated the percentage of upslope forested area containing conifers with an average DBH greater than 20 inches. Sub-alpine areas were excluded from this analysis. In both wet and dry areas of the east side, we calculated the percentage of the forested riparian area (within the 30 m buffer) containing conifers greater than 20 inches DBH.

Average fire condition class was determined for each east-side watershed. Fire condition classes include fire regimes developed from the Land Type Association layer and fuel condition classes, derived from vegetation, crown closure, and slope. The average fire condition class calculation was based on the average class in the watershed, weighted by the area of the watershed in each class.

Assessment of Watershed Condition

Decision support models were used to assess the condition of individual watersheds. These models are computer-based models that capture evaluation procedures and apply a consistent decision or evaluation process across time and space. Reeves et al. (2004) recommended using these models because they are transparent and easy to replicate. The transparent quality of the model facilitates explaining how the assessment was conducted.

Decision support models use data to evaluate a premise. For this analysis, we evaluate the premise that watersheds are in good condition. Data used in the assessment lend varying levels of support to that premise, ranging from full support to no support. We developed criteria to evaluate each attribute based on data and professional judgment. Data on individual attributes were compared to these criteria and given an evaluation score that ranges between +1 and −1, where +1 indicates full support and −1 indicates no support for the premise. Evaluation scores for the attributes were aggregated into an overall assessment of watershed condition. User-defined rules produce an aggregated score weighted toward the resource with either the highest or lowest evaluation score, or a score can be based on the weighted or unweighted average of the indicator evaluation scores. Selection of the rules was based on professional judgment that relied on knowledge of the watersheds and ecological processes. In the models used in this analysis, evaluation scores were typically aggregated using either a weighted or unweighted average. Weights were assigned based on the experts' opinions about the relative importance of individual attributes in contributing to the condition of watersheds. In a few cases, an aggregated score weighted toward the lowest evaluation score was used to allow a single variable to override other variables.

A decision support model was built, refined, and peer-reviewed for each physiographic province to account for the ecological differences that exist between provinces. The workshops consisted of an informal group process through which local experts came to consensus on the model structure and evaluation criteria. After the workshops, models were built and run and the results were returned to the workshop participants. Participants compared the results of the model to their knowledge of the condition of the watersheds and suggested refinements to the model as necessary. Changes were made to the model and the results were re-evaluated.

Sensitivity Analysis

Each of the decision support models was analyzed to determine how sensitive it was to changes in individual watershed attributes. This evaluation differed than typical sensitivity analyses that vary the model parameters to determine how the results are affected by their values. Here we make a first attempt at developing relationships between management activities (road building and decommissioning and vegetation harvest) and watershed condition score. For each attribute, we selected the value that would produce an evaluation score of 0 as a starting point (selected for ease of interpretation) and then changed the value of that attribute by 5, 25, 50, and 100 percent in a direction intended to improve watershed condition scores (for example, road-related attributes were decreased). We ran each model on the data set generated for the analysis and examined the effect of changing each attribute on the watershed condition score.

Two main factors influence the sensitivity of the models: the evaluation criteria used and the weights given to individual attributes. Curves generally have one of two shapes, linear or asymptotic. Asymptotes occur at the point that the attribute data evaluated meet or exceed the +1 (or -1) evaluation curve value. Linear curves describe attribute data that have yet to approach the asymptote. The magnitude of change that can occur before reaching the asymptote is related to the distance (in terms of the units of the attribute data evaluated) between the -1 and +1 evaluation criteria values. For example, the percentage of cover of conifer greater then 20 inches in diameter at breast height in the riparian zone can increase by 25 percent before the asymptote is achieved (Figure 4). Once the asymptote is achieved, then additional decrease in the hazard road density will not contribute positively to the watershed condition score. The asymptote that corresponds to the -1 evaluation criterion indicates the attribute level that must be reached before the condition score increases. As an example, watersheds that have road-stream crossing frequency greater than or equal to 4 crossings per mile of stream will receive an evaluation score of -1 (Table 3). Therefore, road-stream crossings in these watersheds must be reduced to 4 crossings per mile of stream before any improvement in watershed condition will be realized.

MODEL DESCRIPTION AND INTERPRETATION

Watershed and reach condition scores are presented in the model output table in the watershed data summary document. These scores were calculated by evaluating individual attributes and then aggregating their evaluation scores.

How the model works

The North Cascades province model includes an evaluation of both watershed and reach-scale attributes. The model hierarchically aggregates data from a number of attributes into broader indices of reach and watershed condition. For example, the reach condition score also serves as one component of the broader watershed condition score. In this case, the reach condition score used in the watershed model is the average of the evaluation scores of all the reaches in the watershed. A graphical depiction of the model structure for the North Cascades province is presented in Figures 5 and 6. In this iteration, some model sections were "turned off" because the corresponding data were not available. These unused portions of the models are indicated in gray on the diagram.

The model begins by reading a set of data observations, which we call "attributes" for a watershed. These attributes are the right-most nodes in the model structure diagrams. For example, water temperature (maximum seven-day average) is an attribute of the watershed condition model. When the provincial experts constructed the model structure, they also developed evaluation criteria for each attribute. The attributes and evaluation criteria that make up the watershed and reach condition models are described in Tables 3 and 4.

The watershed model attributes column contains the attribute name, units of measure and qualifiers, if there are any. For example, upslope vegetation is evaluated differently depending on whether the watershed is located on the east side or west side of the Cascades. The data value and evaluation score columns show how the data values correspond to evaluated scores. The curve shape column gives a graphical depiction of the relationship, with data values represented on the x-axis and corresponding evaluation scores on the y-axis (Table 3). The evaluation curves depict how each data value is scored on a scale from +1 to -1, according to its contribution toward overall watershed condition. As attribute data are read into the model, they are compared to the evaluation criteria to produce an evaluation score between +1 and -1. The source column gives the basis on which the curve was constructed, which is most often the professional judgment of workshop participants, but also includes datasets, published reports or standards.

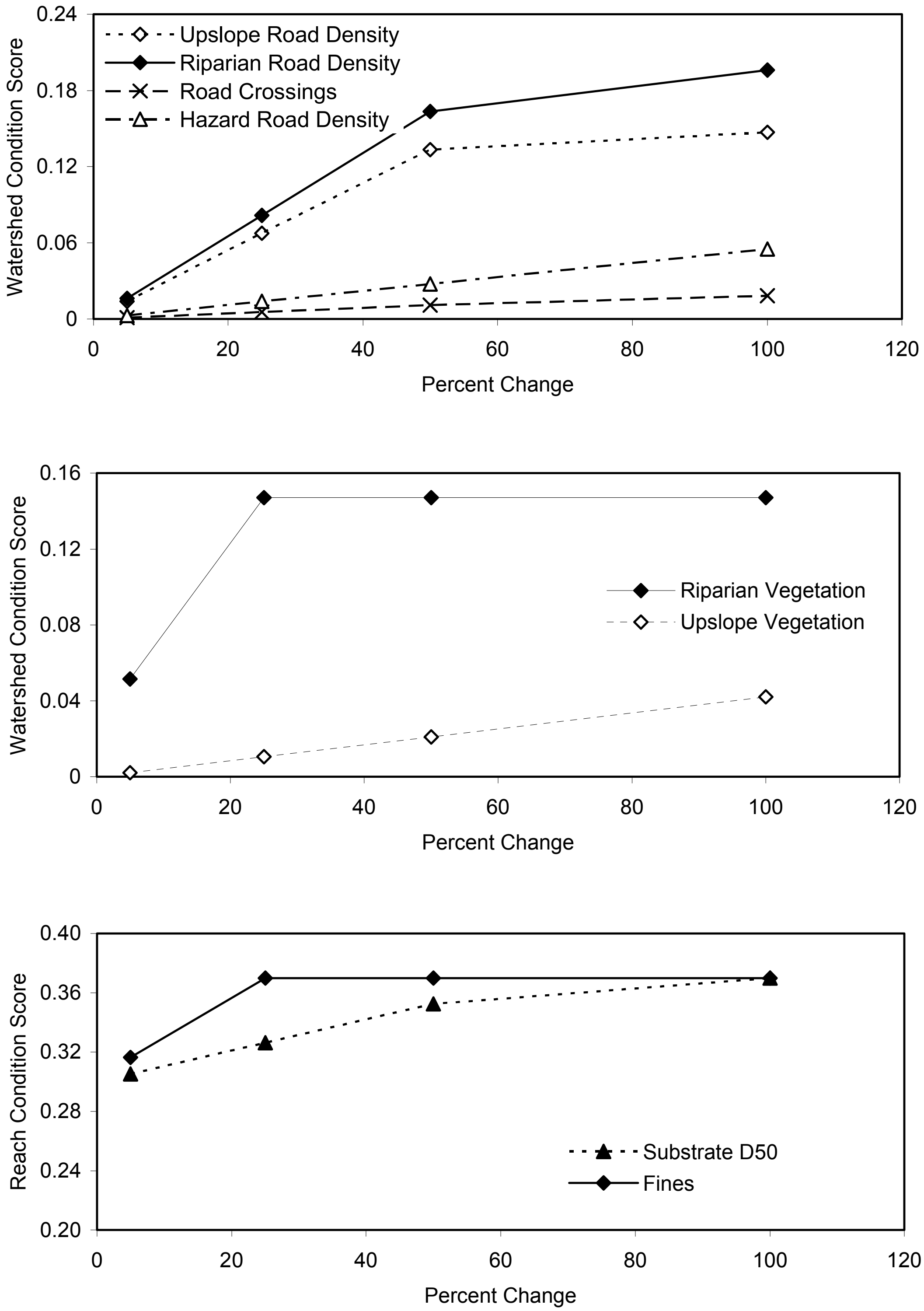


Figure 4. Sensitivity analysis results from the decision support model used to evaluate watershed condition in the North Cascades. Road attributes are presented in the top panel, vegetation attributes in the center panel, and in-channel attributes in the bottom panel. X-axis values represent percent change in each of the attributes. Y-axis values are the watershed condition scores derived from the model.

For example, in the North Cascades province, if there are no roads within 20m of the stream at any point in the watershed (riparian road density = 0%), then the evaluation score would be +1 because it is less than the node-x value of 5; if the percentage of stream length with a road within 20m was 20% or greater, the score would be -1; and if the density falls between 5% and 20%, the attribute receives a score that is a linear interpolation between +1 and -1 (for example 12.5% would evaluate to 0). Note that there is an important difference between a data value of "zero" and "no data". Data values of zero (as in the lower-slope road density example above) are compared to their evaluation curve in the same way as all other data values.

After each attribute datum is evaluated, the model aggregates the attribute evaluation scores together in a hierarchical fashion. The combined score is passed up to the next level in the model hierarchy where it is combined with results from other parts of the model (Figure 5). To assign levels of importance to different variables, the model uses two different operators to aggregate the evaluation scores: MIN, where it takes the minimum score from those being aggregated, and AVE, where it averages the scores. These functions reflect whether the attribute is a "limiting factor" type and the worst condition score determines the combined score (MIN), or a "partially compensatory" situation, where scores are all counted equally (AVE). In addition to operators, each node in the model can also be assigned a weight. For example, the North Cascades watershed condition model weighted riparian vegetation at 0.7 and upslope vegetation at 0.3, so the overall vegetation score comes 70% from the riparian value and 30% from the upland value. The weights are only relevant under the AVE operator.

Reach condition scores were determined in a similar fashion to watershed condition scores. Attribute data values were assigned evaluation scores which were aggregated using operators, and assigned weights to obtain an overall reach condition score (Figure 6 and Table 5).

How to Interpret the Assessment of Watershed Condition

The Assessment of Watershed Condition table in the watershed data summary document presents the evaluation scores from the top down, in an outline format. The indented attributes represent the contributing attributes with their data values and corresponding evaluation scores. At each higher level of the outline, the aggregation of the contributing evaluation scores is displayed, consistent with Figure 5. Reach condition scores for each of the sites that were surveyed in the watershed are presented in the table below with the sites listed from left to right. The tab left of the model output tab in the excel document contains a data dictionary explaining each of the attributes that were evaluated in the model, listed in the same order as on the Watershed Condition table.

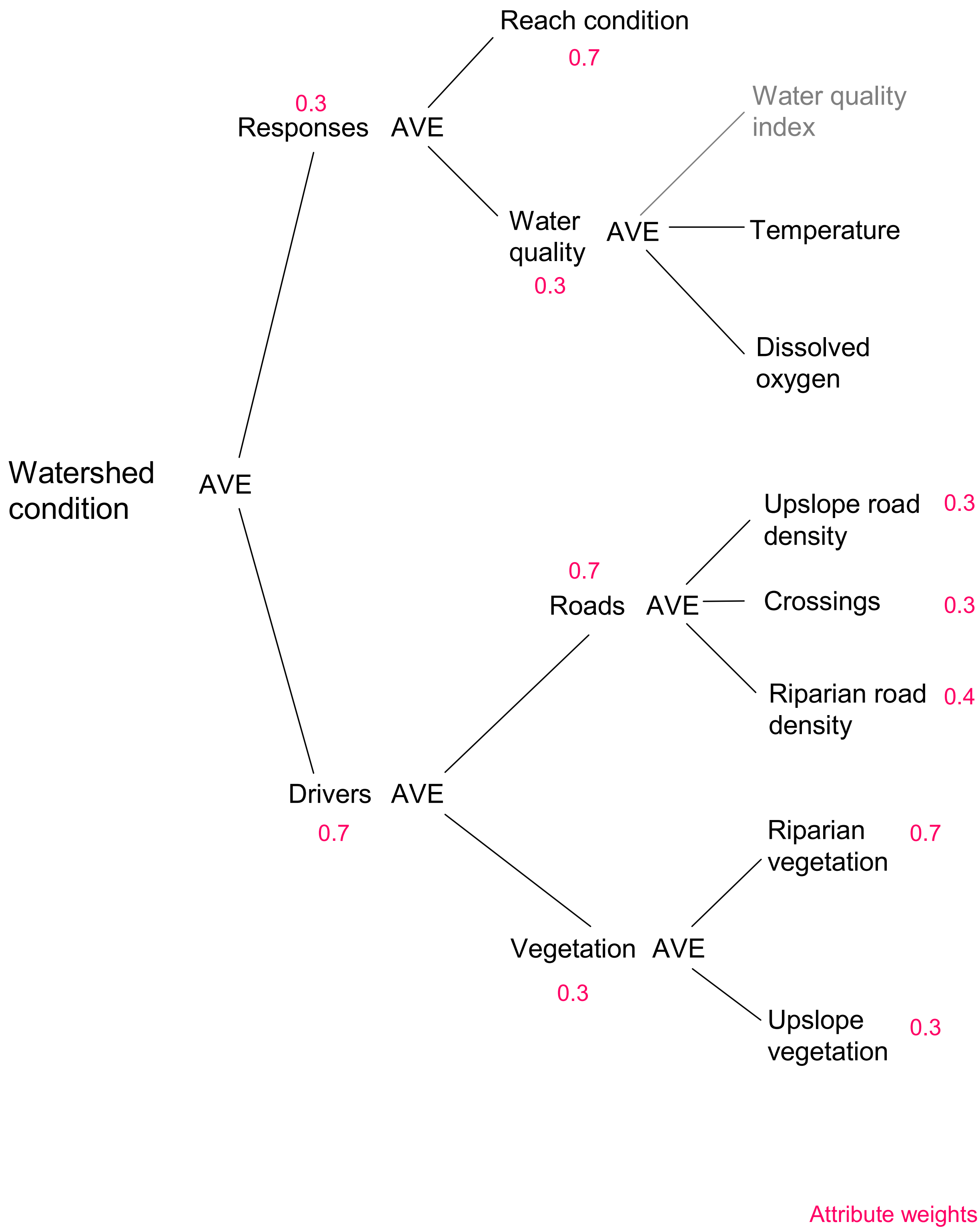


Figure 5. Graphical depiction of the watershed model structure for the North Cascades Province. The right-most nodes in the diagram represent watershed attributes that are evaluated and given an evaluation score. Evaluation scores are aggregated using the operators and weights depicted on the diagram to calculate an overall watershed condition score.

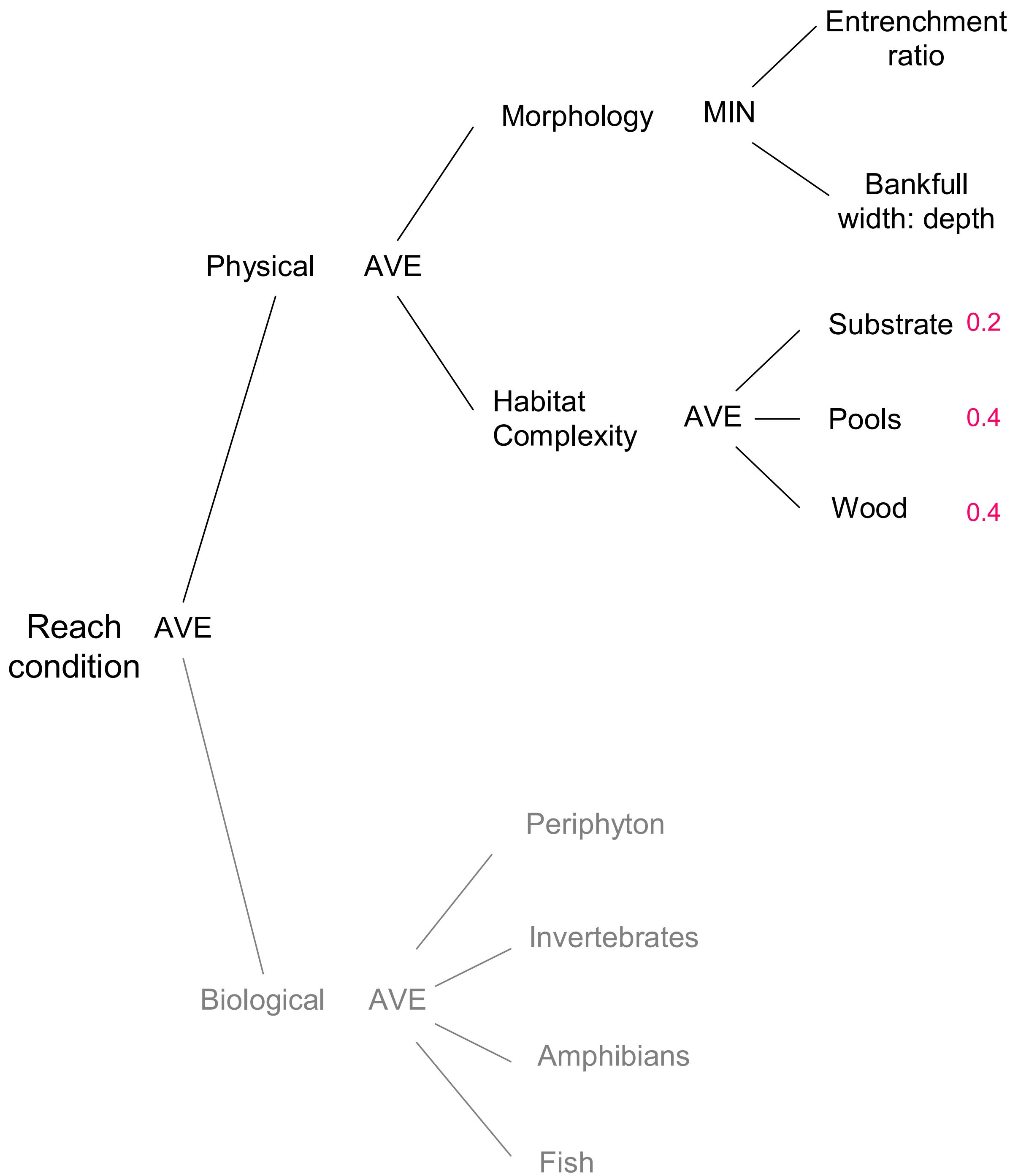


Figure 6. Graphical depiction of the reach model structure for the North Cascades Province. The right-most nodes in the diagram represent reach attributes that are evaluated and given an evaluation score. Evaluation scores are aggregated using the operators and weights depicted on the diagram to calculate an overall watershed condition score. Reach condition scores are an attribute of the watershed condition model.

Table 3. Watershed model attributes and evaluation criteria for the North Cascades Province.

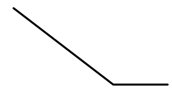
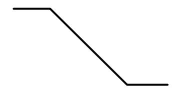
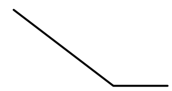
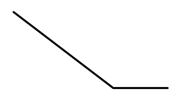
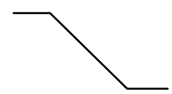
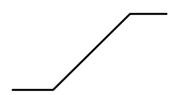
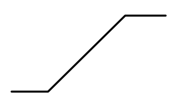
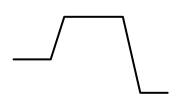
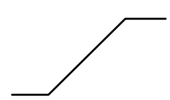
Watershed model attributes	**Data value** Node x-value	**Evaluation score** Node y-value	**Curve shape**	**Source**
Upslope road density mi road / mi² watershed	0.7 2.4	1 -1		King (N ID); Cederholm & Reed AREMP Workshop 4/28/03
Riparian road density % stream mi w/road within 20m	5 20	1 -1		Professional judgment AREMP Workshop 7/1/04
Road crossing frequency hazard areas # crossings / mi² watershed	0 4	1 -1		Professional judgment AREMP Workshop 4/28/03
Road crossing frequency non-hazard areas # crossings / mi² watershed	0 20	1 -1		Professional judgment AREMP Workshop 4/28/03
Upslope vegetation *East side of Cascades* area-weighted average of fire condition class in miles²	1 3	1 -1		Professional judgment AREMP Workshop 7/1/04
Upslope vegetation *West side of Cascades* % area with canopy cover > 70%	65 88	-1 1		Workshop follow-up Gary Ketcheson AREMP Workshop 4/28/03
Riparian vegetation Large conifer cover % area with conifers > 20" dbh 50m buffer - west side of Cascades 30m buffer - east side of Cascades	65 88	-1 1		AREMP Workshop 4/28/03
Water temperature maximum 7-day average °C	4 6 15 18	0 1 1 -1		AREMP Workshop 7/1/04 Ken MacDonald
Dissolved Oxygen mg/L	5 10	-1 1		

Table 4. Reach model attributes and evaluation criteria for the North Cascades Province

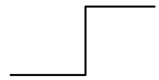
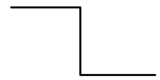
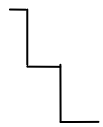
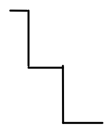
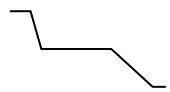
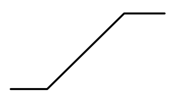
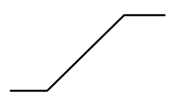
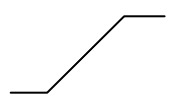
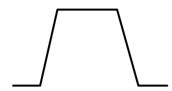
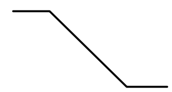
Reach model attributes	Data value Node x-value	Evaluation score Node y-value	Curve shape	Source
Entrenchment ratio				
East side of Cascades	≤ 1.4	-1		Professional judgment AREMP Workshop 4/28/03
	> 1.4	1		
West side of Cascades	≤ 1.2	-1		R. Glesne data DSM NOCA Data recommendations.ppt
	> 1.2	1		
Bankfull width: depth				
East side of Cascades	≤ 40	1		AREMP Workshop 4/28/03
	> 40	-1		
West side of Cascades	≤ 55	1		R. Glesne data DSM NOCA Data recommendations.ppt
	> 55	-1		
Pool frequency				
# bankfull widths per pool				
Eastside gradient > 2%	<1	1		Montgomery and Buffington (1993)
	1	0		
	4	0		
	>4	-1		
Eastside gradient ≤ 2%	< 5	1		Montgomery and Buffington (1993)
	5	0		
	7	0		
	> 7	-1		
Westside - all gradients	≤ 4	1		Glesne data DSM NOCA Data recommendations.ppt
	5	0		
	14	0		
	18	-1		
Wood frequency				
Eastside (western subsections)	1.6	-1		Dawson data wen_subsec_lwd 2004-07-22.xls
# pieces per 100 m	3.1	0		
12" x 50' minimum	4.5	1		
Eastside (eastern subsections)	0.9	-1		Dawson data wen_subsec_lwd 2004-07-22.xls
	1.9	0		
	2.8	1		DSM NOCA Data recommendations.ppt
Westside < 3% slope	0.5	-1		Glesne data DSM NOCA Data recommendations.ppt
# pieces per 100 m	2.5	0		
12" x 25' minimum	7.5	1		

Table 4. Continued

Reach model attributes	Data value Node x-value	Evaluation score Node y-value	Curve shape	Source
Substrate D50	20	-1		Professional judgment AREMP Workshop 4/28/03
mm	30	1		
	100	1		
	500	-1		
Substrate pool tail fines	11	1		Professional judgment AREMP Workshop 4/28/03
%	17	-1		

Data and Information Included with the Watershed Condition Output:

- Watershed map with sample sites
- Photos from the sample sites
- Data Summary – Tables containing watershed condition scores and summaries of GIS and field data
  - Data Dictionary
  - Model Output
  - Watershed Attributes
  - Reach Attributes
  - Biological Attributes
- GIS coverages used in the analysis
- Data – Tables containing raw field data collected during the field season
  - Data Dictionary
  - Watershed Attributes
  - Reach Attributes
  - Pool Residual Depth
  - Wood
  - Vertebrates Aquatic
  - Vertebrates Terrestrial
  - Vertebrates Incidental
  - Thermograph Data

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